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TROPOSPHERIC SOUNDERS

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This presentation is a bit more specific in that the discussion of tropospheric sounders will be about passive, infrared, nadir-viewing sensors, and in particular, the MAPS and TRACER experiments. What is discussed in a general way is the gases measured, the output data products, the data rates, data flow, and data processing for this type of experiment.

The Measurement of Air Pollution Satellites (MAPS) experiment is a nadir-viewing gas correlation filter radiometer that has flown on the space shuttle in 1981 and 1984. The Tropospheric Radiometer for Atmospheric Chemistry and Environment Research (TRACER) is a proposed multi-level gas correlation filter radiometer experiment proposed for Eos and has received Phase I approval.

THE MAPS EXPERIMENT

The primary gas measured by MAPS is carbon monoxide (CO) which is photochemically active and represents the major sink for the hydroxyl (OH) radical in the troposphere. Since OH is the principal oxidizer for most reduced species in the atmosphere, changing levels of CO will alter the chemical processes in this region. Although there is uncertainty in the magnitudes, the sources and sinks of CO are thought to be well known. CO is naturally produced as a result of the oxidation of methane and other hydrocarbons and is destroyed principally as a result of photochemical processes. Man's contribution is thought to be nearly as large as natural sources. Some of the impacts of CO as a pollutant are listed in figure 1.

Some highlights of figure 1 are that the anthropogenic source consists primarily of technological sources (concentrated in the Northern Hemisphere) and biomass burning (concentrated in the tropics). One of the more important results of the first MAPS flight in 1981 was the measurement of large longitudinal gradients. Up until that time the few extrapolations of the measurements of CO had led to the interpretation of global latitudinal variations with the expectation of little or no longitudinal differences.

Figure 2 is a simplified pictorial schematic of a gas filter radiometer. Energy emitted by or reflected from the surface of the Earth propagates through the atmosphere and is gathered by the nadir-viewing instrument. As the radiation passes through the atmosphere, it undergoes selective absorption and reemission that varies depending on the composition, temperature, and pressure of the atmosphere. After entering the instrument, the radiation is divided and directed in parallel through a system of gas-filled cells. The energy transmitted through the cells then passes to a detection system. Because the gas in the cells acts as a highly selective filter, there is generally a difference in the energy transmitted to the detection system through the various cells. The difference in the signals is related to both the amount of gas in the atmosphere with absorption features that correlate with those of the gas in the cells and the height of that gas in the atmosphere. If one of the cells is evacuated, the energy passing directly through the vacuum cell is a measure of the scene brightness. If none of the cells is evacuated, the scene brightness in the passband must be measured separately. Combining this scene brightness measurement (called L), a difference signal between the vacuum and gas cell paths (called ΔL) and knowledge of certain atmospheric parameters (such as the temperature profile) through a numerical radiative transfer program allows inference of the atmospheric mixing ratio of CO.

Figure 3 shows the normalized signal functions for the MAPS instrument as configured for the 1981 shuttle flights. These functions are similar to the weighting functions associated in temperature sounding. The peak of the signal function occurs in the troposphere and the signal goes to zero at the top of the atmosphere where the density decreases to zero. The signal function also goes to zero near the surface since the signal is a function of the temperature contrast between the boundary surface and the atmosphere. The integral of the signal function multiplied by the normalization constant results in the actual radiance measured by the instrument.

Figure 4 is a plot of the infrared CO mixing ratios from the 1981 shuttle flight. The CO mixing ratios have been averaged and plotted in a $5^\circ \times 5^\circ$ box on a mercator projection. Because of shuttle cooling problems, this data is only a 3-hour portion of 12 hours of data that was taken between two reliable calibrations.

Figure 5 is the same type of plot for the 1984 shuttle flight. The CO mixing ratios here are an 8-day average CO mixing ratio averaged over a $5^\circ \times 5^\circ$ box. Both figures 4 and 5 are one of the primary data output products and clearly show the large longitudinal variations in CO mixing ratios that had not been previously seen or predicted before these measurements. In particular, notice the high values over South America and South Africa due to biomass burning, and also over Europe and China due to industrialization. The longitudinal variations are larger than the latitudinal variations for this particular time of the year.

THE Eos TRACER EXPERIMENT

TRACER is a gas correlation filter radiometer proposed and accepted for Phase I definition studies in the Eos program. The Principal Investigator is Henry G. Reichle, Jr. of NASA LaRC. Table 1 shows the general science objectives for the experiment. The orbit and duration of the Eos platform offer a unique opportunity to measure the global and time-dependent distribution of CO. These same conditions mean that the data will be a unique set to be analyzed for transport and chemical studies and for the determination of source and sinks. Also listed in Table 1 is a synopsis of the instrument description.

The instrument is a passive nadir-viewing gas filter radiometer operating at wavelengths of 2.3 and 4.6 μm. The basic concept of the instrument is the same as was shown schematically in figure 2. The implementation of the instrument is different in that it will have a different electrical and optical method of detecting radiances and that the instrument control signal and data processing will be handled by an onboard digital computer. Table 2 lists the TRACER co-investigators, their affiliation, and their primary areas of interest. The co-investigators are divided into two groups: the science team and the experiment team. The science team is primarily outside of LaRC and members may be replaced over the long lifetime of this experiment. The experiment team are all from LaRC and are expected to remain with the project for its lifetime and thus provide a cohesive memory of the goals, design, and implementation of the experiment.

As stated previously, the TRACER concept is basically the same as MAPS in that they are both passive nadir-infrared gas filter radiometers with three major differences. The first is that TRACER has two wavelength regions: 4.6- and 2.3-μm. The second is that optics are different; TRACER will use rotating gas cells rather than choppers and beam splitting. The third is that signal differencing, signal processing, housekeeping, and instrument control will be handled by an onboard computer which is part of the instrument package. The inserts in figure 6 are the gas cell conditions that are used to determine the difference signal for plotted signal functions.

The normalized signal functions for the TRACER instrument are shown in figure 6. As can be seen from the figure, the instrument will measure CO mixing ratios at several levels of the atmosphere. The lower, mid, and upper tropospheric levels are all measured using the 4.6-μm channel. CO in the mixing layer of the atmosphere is measured using reflected sunlight at 2.3 μm. The signals for these measurements are achieved by rotating fixed-length, fixed-pressure gas cells through the optical beam. There are two additional gas cells on the rotating wheel. These cells are filled with nitrous oxide (N_2O) and methane (CH_4). These cells are used in an enhanced data correction technique, which allows the data inversion algorithms to be adjusted for variables such as the presence of clouds, common channel error, and to reduce the effects of false correlation from other gases in the atmosphere.

As part of the design, the TRACER instrument will incorporate the MAST 1750A computer. This computer will handle the data sampling, data digitization, signal differencing, data storage, data formatting, and data transfer. The computer will control the instrument operation and sequencing including internal calibration sequencing. Finally, the computer will perform preliminary data inversions to arrive at CO mixing ratios based on the spacecraft ephemeris and climatalogical atmospheric models. The results of this preliminary data reduction will be merged into the output data stream and can serve as an Eos level-2a data product. The computer will be capable of reprogramming from the ground on the data uplink. This will let the instrument and experiment evolve during the expected 5-year mission duration.

Figure 7 is from the TRACER proposal which shows the general data flow and dissemination plan. Notice on this figure the boxes with no shading on either edge. These are the functions and programs that are to be handled by EosDIS. All of the other boxes indicate software and production handled at LaRC at either pre- or post-launch. For the ISES concept, the unshaded boxes would be the only candidates available for processing onboard the spacecraft. Using an ISES onboard computer would be very redundant because these programs will be executed onboard by the TRACER MAST 1750A computer, on the ground by the EosDIS computer, and also executed at LaRC.

Table 3 is also from the TRACER proposal and shows the expected TRACER processing requirements from input through final output for the various experiment parameters for each of the Eos levels. The main point of this table is to show the low data rates for the TRACER experiment. The final output product will be four CO mixing ratios every second. The peak data rate for the experiment, including all housekeeping, is expected to be 10 kbs.

In summary, TRACER is a semi-autonomous package with very low data rates only requiring access to the platform data bus and platform power. The integral computer exceeds the present instrument design requirements and will probably be reprogrammed to meet future experiment and instrument design changes required as the experiment evolves over a 5-year lifetime.

Table I. TRACER Experiment Science Objectives and Instrument Description

P.I. SCIENCE INVESTIGATION

SCIENCE OBJECTIVES:

- TO DETERMINE THE LONG TERM, TIME-DEPENDENT, THREE DIMENSIONAL, GLOBAL DISTRIBUTION OF TROPOSPHERIC CARBON MONOXIDE
- TO APPLY THESE DATA TO THE DETERMINATION OF SOURCE STRENGTHS, TO THE ELUCIDATION OF VERTICAL AND HORIZONTAL TRANSPORT PROCESSES, AND TO THE DEVELOPMENT AND VERIFICATION OF GLOBAL CHEMICAL-TRANSPORT MODELS

INSTRUMENT DESCRIPTION:

- NADIR-VIEWING GAS FILTER RADIOMETER OPERATING AT 2.33 μm AND 4.67 μm
- SIGNAL DIFFERENCES ARE FORMED BY ROTATING FIXED-PRESSURE, FIXED-PATH LENGTH GAS CELLS THROUGH THE OPTICAL PATH
- ALL SIGNAL PROCESSING, INSTRUMENT CONTROL, AND DATA PROCESSING FUNCTIONS HANDLED VIA ONBOARD DIGITAL COMPUTER

Table II. TRACER Co-investigators

SCIENCE TEAM

Paul Fraser	CSIRO, CO Measurements
Michael Garstang	U. Va, Atmospheric Motions
Ivar Isaksen	U. Oslo, Chemical/Transport Modeling
Ralph Nicholls	York U., Instrument/Rad. Transfer
Wolfgang Seiler	Fraunhofer Inst., Co Measurements
Jennifer Logan	Harvard U, Chemical/Transport Modeling
Reginald Newell	MIT, Atmospheric Motions
Ronald Prinn	MIT, Chemical/Transport Modeling

EXPERIMENT TEAM

Vickie Connors	Atmospheric Motions
Jack Fishman	Chemical Modeling
Curtis Rinsland	CO Meas./Spectroscopy
H. Andrew Wallio	Radiative Transfer/Instrument

Table III. TRACER Input, Output, and Processing Requirements

(a) - Input Data

Input Data Description	Eos Level	Data Source	Peak Rate (Mbits/sec)	Volume (Mbits/day)	Temporal Resolution	Spatial Resolution
Raw telemetry data	0	Raw TM	0.01	864	1 sec	20 km Raw
Tracking data	0	TDRSS	Small	5.6	1 min	500 km
Calibrated engineering units	1a	Eos L0	0.01	864	1 sec	20 km
Ephemeris data	1a	Eos L0	Small	5.6	1 min	500 m
Calibrated radiances	1b	Eos L0	0.01	980	1 sec	20 km
Mixing ratio	2a	Eos L1b	0.01	1220	1 sec	20 km

(b) - Output Data Products

Output Data Description	Eos Level	Units	Volume (Mbits/day)	Temporal Resolution	Spatial Resolution
Level 0 telemetry data	0	Counts	864	1 sec	20 km
Telemetry reports	0		small	Daily	
Calibrated engineering units	1a	Volts, temp	864	1 sec	20 km
Ephemeris data	1a	m, m/s	5.6	1 min	500 m
Ephemeris reports	1a		small	Weekly	
Level 1a reports	1a		small	Daily	
Calibrated radiances	1b	$W\ cm^{-2} sr^{-1}$	980	1 sec	20 km
Level 1b reports	1b		small	Daily	
Mixing ratios	2a	ppbv	980	1 sec	20 km
Level 2a reports	2a		small	Daily	
Correlative validated mixing ratios	2b	ppbv	980	1 sec	20 km
Level 2b reports	2b		small	1 year	Global

(c) - Data Processing Requirements

Processing Step	Level	Lines of Code	Operations Data Day	Frequency
Decommutation, reformatting	0	24,000	7×10^9	Daily
Location, calibration	1a	12,000	12×10^9	Daily
Radiance Measurements	1b	8,000	13×10^9	Daily
Mixing Ratios	2a	13,000	26×10^9	Daily
Data Validation	2b	8,000	4×10^9	Daily

A Pollutant of Global Impact

- CO represents over 50% of total U.S. pollutant emissions
- Man's contribution is estimated to be about 50% of the total flux
- Technical sources are concentrated in the northern midlatitudes
- Biomass burning is concentrated in the tropics
- Model studies show
  - Present emissions are sufficient to perturb global CO-CH_4-OH chemistry
  - Time constants are long (10 - 30 years)
  - Possible impact on stratospheric chemistry and planetary heat balance
- Longitudinal variations were unknown prior to MAPS flight

Figure 1. Importance of trace gas carbon monoxide.

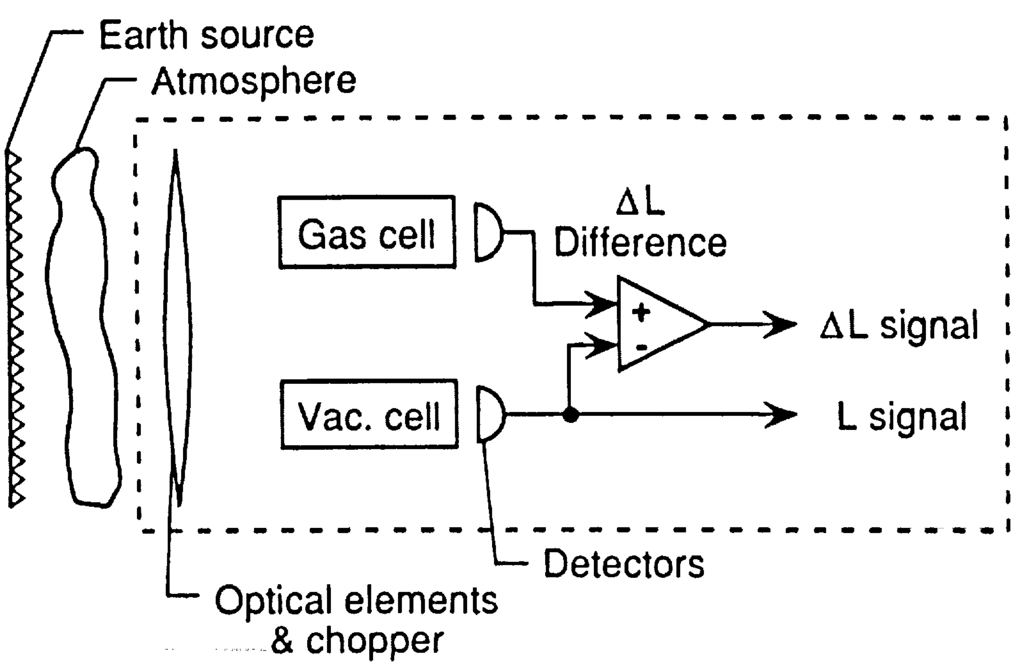

Figure 2. Schematic diagram of the instrument.

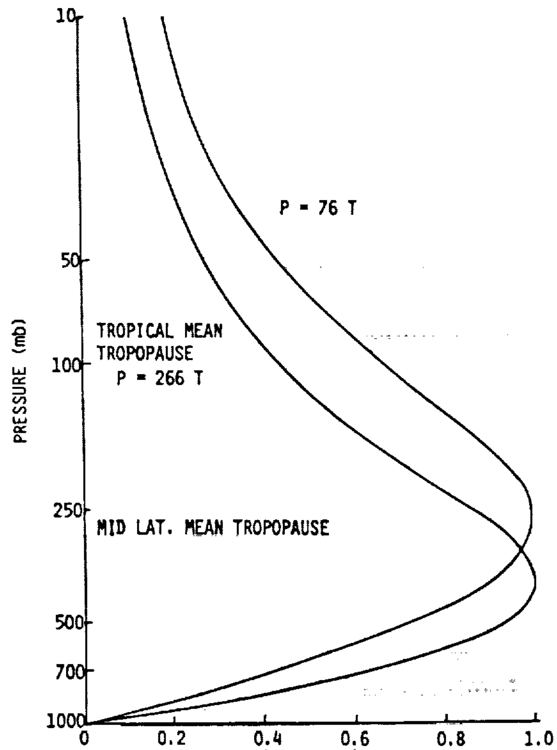

Figure 3. Normalized signal function for OSTA-1 MAPS Experiment.

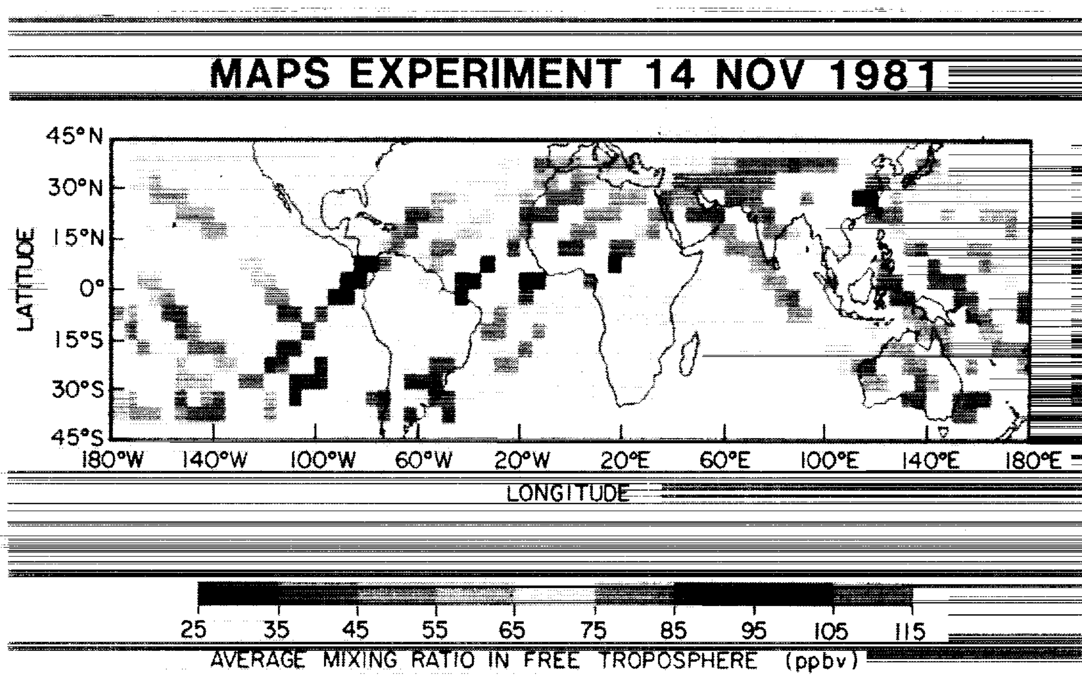

Figure 4. Averaged tropospheric carbon monoxide ratios measured by MAPS instrument during OSTA-1 flight.

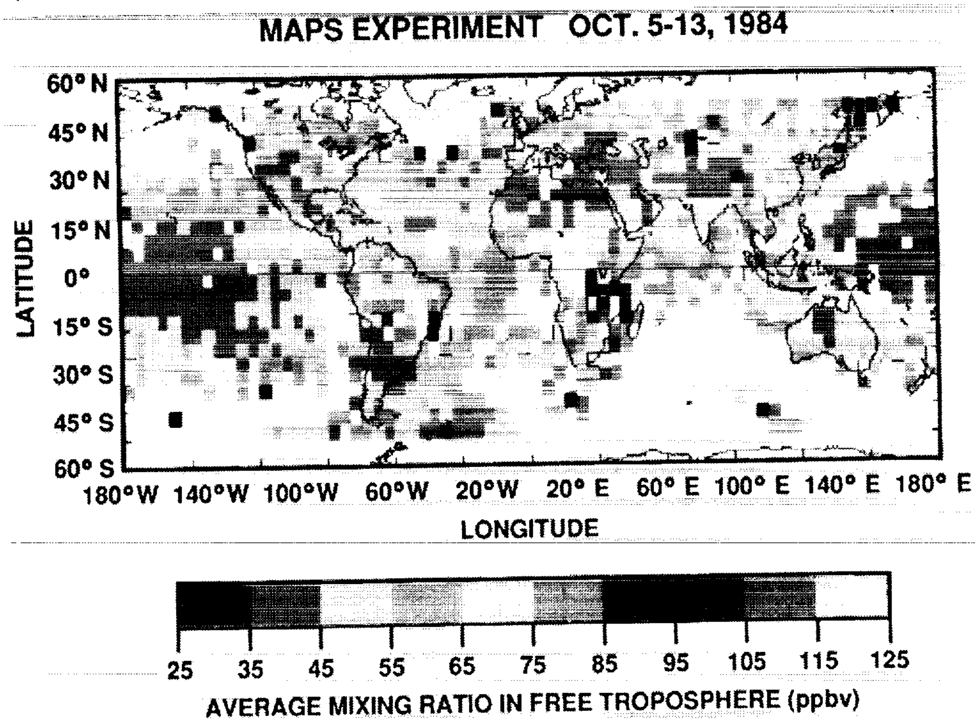

Figure 5. Average tropospheric carbon monoxide ratios measured by MAPS instrument during the OSTA-3 flight.

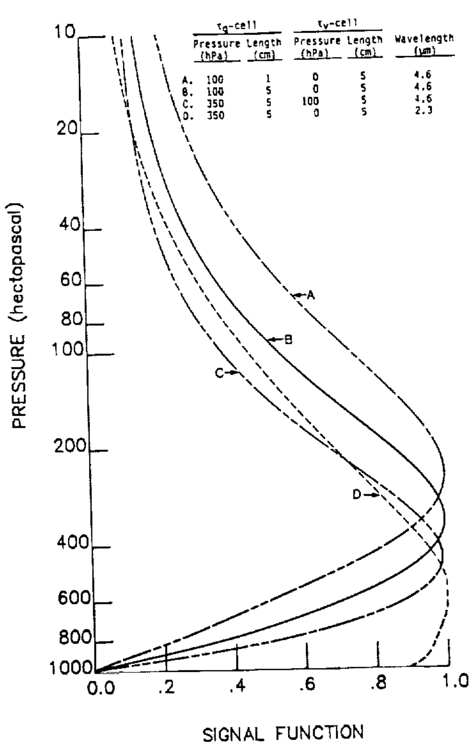

Figure 6. Normalized signal functions for the TRACER experiment.

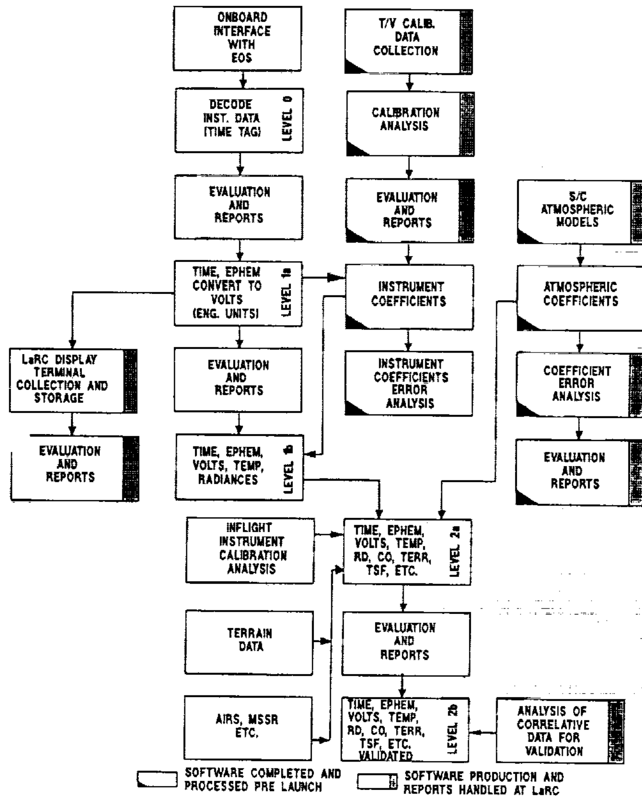

Figure 7. Data flow and dissemination plan for the TRACER experiment.